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## Electronically-Switched Attenuators

**Attenuators, whether fixed or variable, have a very definite place in the realm of radio techniques. They render vital service in such items as signal generators, selective level meters and in radio communications systems.**

In order to determine the optimal functioning of a radio item, the input signal levels must lie between certain fixed limits. In radio receivers especially, the input signal is so varied that it is difficult to come to any sort of prognosis upon it. The receiver must therefore be in the position to automatically adjust itself according to the prevailing signal conditions. This implies that the receiver must present all modules with a signal with which they can handle efficiently and without distortion. Too much signal power leads to inter-modulation distortion and also to the falsification of the S-meter indication owing to saturation effects — the needle remaining practically jammed at full-scale deflection and no meaningful signal-level reading can be carried out.

An attenuator, placed at a suitable point in the signal chain, does help to bring the signal down to a more workable level. Even better would be a continuously variable attenuator with a calibrated scale such as the one described in ref. (1). Often,

however, an attenuator variable in known fixed steps is desired which allows a better appreciation of the input signal strength, or indeed, its measurement.

For many years now, step attenuators have been available commercially whose attenuation may be stepped by a fixed amount either higher or lower. The attenuator range, its insertion loss and input impedance together with its working frequency range are all important specifications in its evaluation and eventual selection. The attenuation adjustment is mostly carried by control potentials at TTL voltages in order that a convenient control circuitry can be developed. A user-friendly step attenuator could have the following criteria specified:—

- Attenuation continuously adjustable in 1 dB steps over the range 0 - 100 decibels.
- Wideband frequency range with negligible VSWR.
- The attenuation is effected by means of UP/DOWN buttons or a decade switch, the set attenuation being indicated on a digital display.

To buy such an item would cost a mint of money but precision would be assured. The radio amateur with a ready access to components can, how-

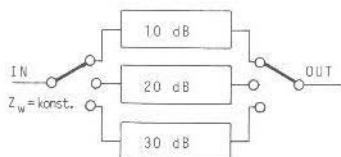


Fig. 1: Various attenuator four-poles with multi-way switch

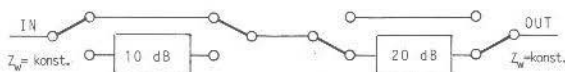


Fig. 2: Series attenuator pads which are either bypassed or inserted to make up the desired total attenuation.

ever, build a step attenuator for relatively little outlay which would entirely suffice for hobby purposes. No exotic parts are required and the technical specification of the finished instrument is worthy of note. The construction of the instrument to be described later in this article can be employed in the VHF range, 2 m and 70 cm bands and in the higher UHF ranges.

## 1. PRINCIPLE

A step switchable attenuator can be realized in one of the following ways:

### 1st Method

a) An attenuator four pole with the various desired values of attenuation can be selected with a multi-way switch as in fig. 1.

b) A specially dimensioned series of attenuators can be either inserted or bypassed in the chain by switches as in fig. 2.

If many attenuation steps are required to be selectable then method a) is unsuitable as one four-pole is selected for each value of attenuation required.

The method b) is to be favoured as the individual elements are more fully utilised. From  $n$  various independent four-pole elements,  $2^n$  different attenuation values may be obtained. For example: If a 20 dB and a 10 dB attenuator pad were

connected in series, the following combinations are possible:

- 0 dB — the two pads bypassed
- 10 dB — only the 20 dB pad bypassed
- 20 dB — only the 10 dB pad bypassed
- 30 dB — both pads connected in series

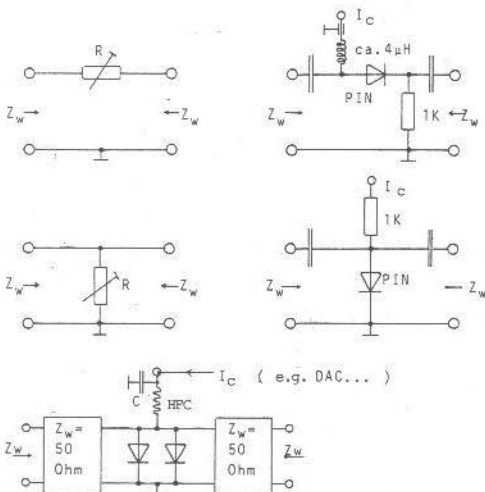
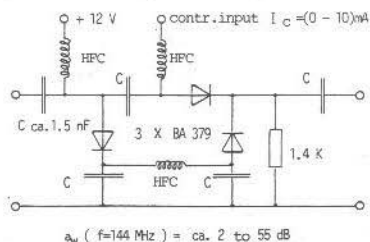


Fig. 3: a) Series attenuator:  
No reflection-free termination  
 $Z = f(R) = (50 - \infty) \Omega$

- b) Parallel attenuator:  
No reflection-free termination  
 $Z = f(R) = (0 - 50) \Omega$

- c) Attenuator with matching circuit  
 $Z = \text{constant (e.g. } 50 \Omega)$

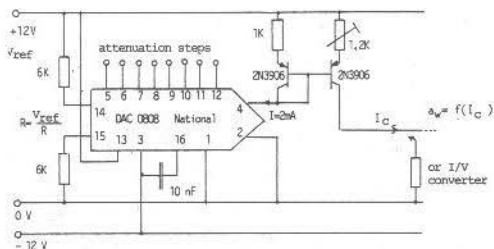


**Fig. 4a: A continuously variable attenuator achieved by a trick circuit (ref. 1). The input and output resistance remains independent of the selected value of attenuation at exactly 50  $\Omega$ .**

A step attenuator from 0 to 30 dB switchable in 10 dB steps, using only two elemental pads, is the outcome.

## 2nd Method

The four-pole attenuators of method 1 all possess a constant, defined input and output resistance of e.g. 50  $\Omega$  — as long as they are constructed in either a 'T' or a 'Pi' network. A definite and a constant-with-frequency characteristic impedance is very important. The controllable PIN-diode attenuator elements from (1) achieve these conditions by means of a circuit trick — but there are also other simpler methods of signal attenuation.



**Fig. 4b: The continuously variable adjustment of the PIN diode attenuator above may be carried out by means of an analogue-to-digital converter. The pre-set potentiometer adjusts the control current to the desired value.**

a) The principle of parallel and series attenuators is shown in **fig. 3**. The variable resistor here can be a resistor capable of working at HF or a PIN diode with the appropriate control circuitry.

This arrangement has the disadvantage that the input/output impedance varies over quite a large range, giving rise to energy reflections. There are circumstances in which a constant characteristic impedance is not absolutely essential. Sometimes a matching circuit must be made in order to keep the input characteristic constant, e.g. with a directional coupler. For frequencies under 1 GHz the complexity is too high. For such frequencies the following solutions are available:

b) The continuously variable attenuators of **fig. 4a** mentioned in (1), both possess a constant input impedance over the frequency range 50 to 800 MHz and at all attenuator settings.

The attenuator setting may be accomplished by means of a DC potentiometer circuit or with the assistance of a digital to analogue converter (DAC). For every combination of bits presented to the DAC (**fig. 4b**), a different value of attenuation is set-up and for which a different value of control current flows.

With the combination of an EPROM and an UP/DOWN switch it is possible to control the attenuation with any degree of required resolution.

The attenuation versus control-current characteristic is not a linear function. The appropriate function:  $a_w = f(\text{cont.})$  must therefore be linearised with the help of an EPROM. The EPROM may be read e.g. with a forwards/backwards counter.

## 2. THE PIN DIODE AS AN HF SWITCH

Modern HF systems are no longer switched by means of relays except for the most special cases. RF coaxial relays are easy in their application but very uneconomical. In other respects too they fall short of the ideal, being slow in operation and they are prone to mechanical wear and tear. They do, however, offer low insertion im-

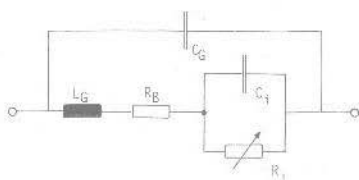


Fig. 5a: HF PIN-diode equivalent circuit

- $C_G$  = Capacity to ground  
 $L_G$  = lead inductance  
 $R_B$  = PCB track resistance  
 $C_i$  = I-Zone capacitance  
 $R_i$  = HF resistance (dependent upon control current)

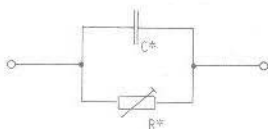


Fig. 5b: Simplified PIN-diode equivalent circuit

- $C^*$  = Total capacitance  
 $R^*$  = Total resistance

pedance and high open-circuit isolation but nevertheless, they are being gradually replaced by the PIN-diode switch. How PIN diodes are able to switch HF energy will now be briefly explained.

### 2.1. What is a PIN-Diode?

PIN diodes are basically silicon diodes. Their mode of operation, as opposed to other types of diodes, is quite easy to understand. In between the P and the N junction, normal to a silicon diode, an additional layer known as the I-zone is introduced. The I stands for "Intrinsic" (hence PIN diode) which means inherently conducting, in this context. The exact physical explanation of how they work is explained elsewhere (2). The PIN-diode characteristics at low frequencies and at DC, are indistinguishable from those of a normal silicon diode, that is, the transfer characteristics are similar.

As the frequency of operation is raised, the PIN-diode characteristics become evident. This

happens at limit frequencies between 1 and 5 MHz. The rectifier action gradually disappears and the device assumes the character of an HF resistor. This HF resistor comprises several components, but in the main they can be compared to an adjustable ohmic resistance. The actual resistance is determined by the amplitude of a control current which is passed through the diode together with the signal to be attenuated. The HF resistance can be varied by these means from a few ohms to several thousand ohms. Because of these characteristics, the PIN diode may be said to be an HF resistor or switch capable of being controlled by a direct current.

### 2.2. PIN-Diode HF Equivalent Circuit

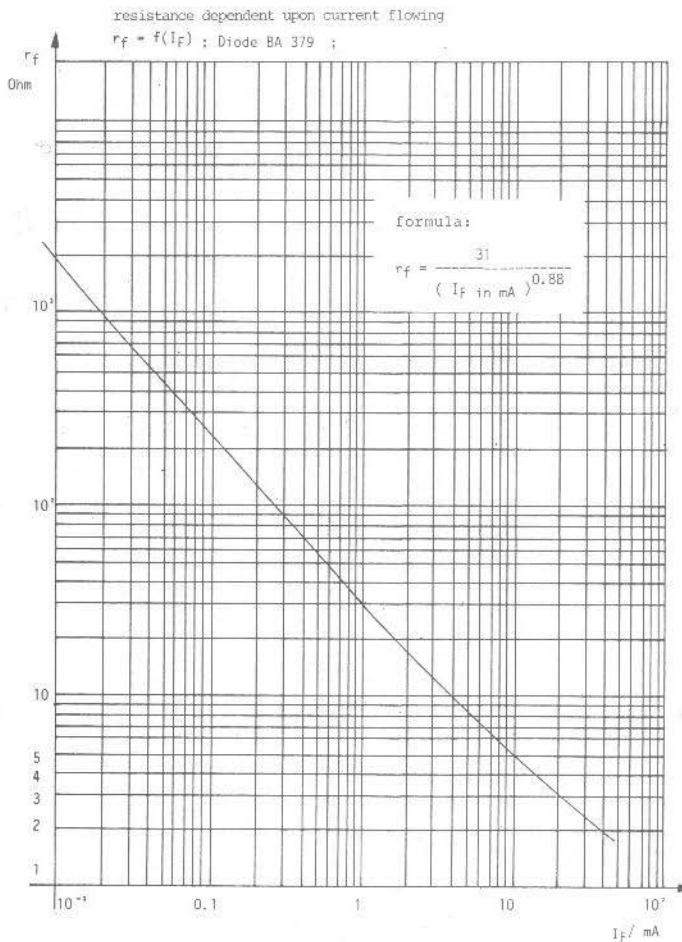
The equivalent circuit of a PIN diode is shown in **fig. 5a**. Examination of this circuit reveals that there exists a definite limit to the frequency which can be handled by the device. These limits vary with the individual types of PIN diodes. Some of the undesirable properties are the parasitic inductance  $L_g$  (approx. 0.7 nH), the ohmic resistance  $R_b$  (approx. 1  $\Omega$ ) and the capacitance  $C_i$  across the I zone. The resistance  $R_i$  represents the desirable property of the device which can be varied between 5  $\Omega$  and 10 k $\Omega$  (approx.). This is the component about which everything else revolves.

The parallel stray capacitance  $C_g$  tends to nullify the resistance  $R_i$  when the resistance is set to the higher values and also with increasing frequency, thus setting an HF limit to its full range operation.

It is, then, typical for every PIN diode to have a frequency specification for which the main resistance band remains within tolerance. The undesirable diode reactances should therefore be kept as small as possible. The characteristic of **fig. 6** shows the dependence of the high-frequency resistance ( $r_i$ ) of the PIN diode upon the controlling direct current  $I_F$ .

### 2.3. The PIN-Diode Switch Function

When the PIN diode is employed as a switch, there are only two functions which are desired. In one condition the diode should have a lower resistance when it is closed and in the other condition, open, it should possess extremely an high resistance. In other words exactly the same



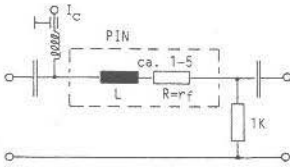
**Fig. 6:**  
Resistance of BA 379 as a  
function of current

properties as one would expect from a mechanically operated electrical switch.

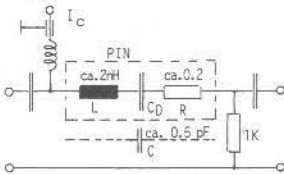
In order to obtain a low-ohmic resistance, the largest permissible control current should flow through the diode — the resistance then is only a few ohms. When this current is removed then the diode reverts to its maximal resistance for that frequency. This high value of resistance can be

maximised by placing a bias across the barrier direction but in general, no great benefits can be expected for the extra complexity involved.

In the 'open' condition the diode resistance is a few thousand ohms but this is frequency dependent and the total circuit resistance varies with both the characteristics of the individual diode and upon the external circuitry involved.

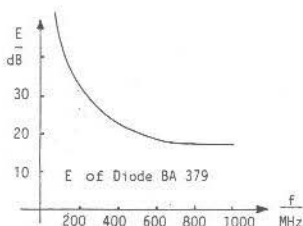


**Fig. 7a: HF equivalent circuit of PIN-diode showing attenuation in the direction of conduction**

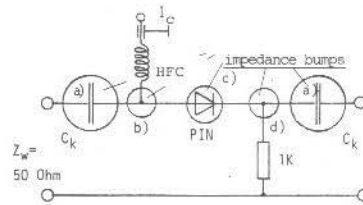


**Fig. 7b: HF equivalent circuit of PIN-diode showing attenuation in the blocked direction**

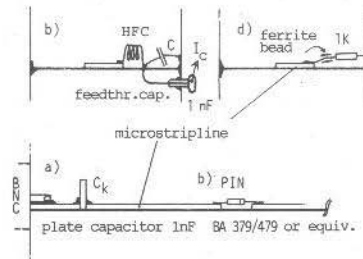
The equivalent circuit of a PIN-diode switch is shown in **fig. 7**. The undesired diode reactances may be partially compensated for by the external connection of both L and C which effectively tunes them out. This measure, of course, is only effective at or near a certain frequency and since most PIN-diode circuits are required to be wide band, resonance effects are normally to be avoided. Later on, a few techniques will be explained which are commonly used in HF circuitry:



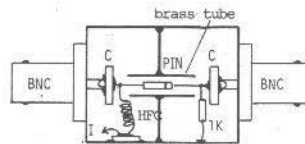
**Fig. 8: The isolation as a function of frequency**



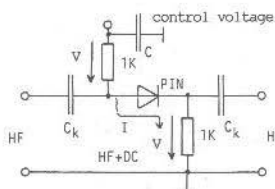
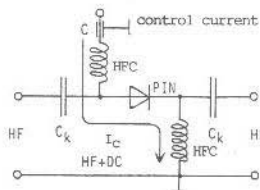
**Fig. 9a: The inclusion of components in a 50  $\Omega$  system gives rise to impedance bumps**



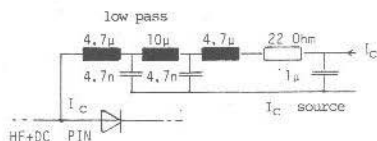
**Fig. 9b: PIN-diode switches constructed in the stripline technique**



**Fig. 9c: Suggested form of PIN-diode switch in coaxial form**



**Figs. 10a/b: Low-pass filter feed for the control current**



**Fig. 10c: Method of control-current feed taken from a Hewlett-Packard circuit.**  
Frequency range: 10 to 1000 MHz

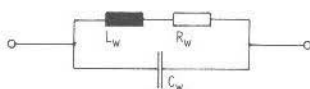
a) Insertion loss: The inclusion of a PIN diode in a circuit always introduces a residual attenuation (fig. 7a).

b) Isolation: The PIN diode in the biased-off state always lets a little RF energy flow through the circuit. The isolation  $I$  is strongly dependent upon the frequency and is expressed in dB. The higher the isolation (dB) the better the 'switch-off' state will be. This is of particular importance for change-over switches because the switched out portion of the circuit should have no influence upon that which is working (fig. 7b). The isolation  $I$  in dB is shown in fig. 8, plotted against frequency.

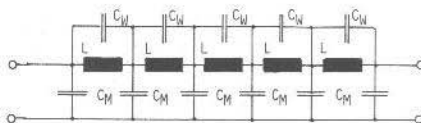
## 2.4. The Control of PIN-Diodes

The control current must be applied carefully as the PIN diode is included normally in a 50  $\Omega$  network. The control current is introduced via means of low-pass filters and is superimposed upon the HF signal to be controlled. These low-pass filters must not be allowed to interfere with the characteristics of the HF circuit. Every additional component, introduced into the 50  $\Omega$  system, brings a potential reflection point with it (fig. 9). In order that the control current be fed in and out of the PIN diode without affecting its operation, the following possibilities may be considered (fig. 10):

a) The DC feed-in is effected by means of wide-band high-frequency chokes which present a high impedance to the working range of frequencies. The direct control current can, of course, flow unhindered through the chokes. This method is used preferably in a pure current control, for example, by a digital-to-analog converter.



**Fig. 11a: Equivalent circuit of one turn on a coil**



**Fig. 11b:**  $L_W$  = Inductance of a turn  
 $C_M$  = Capacitance to ground  
 $C_W$  = Inter-turn capacitance  
At higher frequencies the ohmic component may be neglected but not the self-capacitance

b) The feed-in is effected by HF resistors. These, resistors in relationship to the characteristic impedance of the PIN-diode system, should be correspondingly high — a 50  $\Omega$  system using feed-in resistors of 800 to 1000 ohms. The loading effects upon the PIN-diode system are minimal and therefore the system's return-loss is unimpaired. In order to fully control the diode, 10 to 100 mA are required which necessitates having a rather large control circuit potential — 10 mA through a 1 k $\Omega$  resistance is already a potential difference of 10 V. This means that heat loss in the feed resistors is unavoidable.

The best solution is probably a combination of both method a) and b). The first method has the disadvantage that care must be exercised during testing not to destroy the PIN diode. The second method's disadvantage is that a high-control supply voltage is required.

High-frequency chokes also have their problems. Commercial HCFs normally consist of many windings of fine wire which create quite a large capacitance across the component. The HCF's self-capacitance then resonates with the rated inductance at some frequency. In the interests of a predictable wideband system performance, this resonant frequency should not lie within the band of interest. Also, without resonance effects, a large HCF self-capacitance represents a capacitance directly across the 50  $\Omega$  PIN-diode system



thus tending to shunt away the RF signal energy in an uncontrolled manner. High self-capacity chokes cannot therefore be employed in wide-band attenuator systems. Genuine wideband HFCs covering HF to UHF are very rare components.

The classical VALVO, six-hole ferrite choke core represents an acceptable alternative but in order to improve its performance at high frequencies, a 4-turn, air-cored coil should be used in series with it at the 'hot' end!

Perhaps the best way of getting a suitable HFC is to make one. This can be done by simply winding 8 turns of copper wire around a 3 mm former thus making a self-supporting air-cored inductor. Several HFCs of this kind used in a system may lead to resonance effects but perhaps with luck the frequencies at which resonance occurs will not be used by the system.

The inductance of an air-cored coil may be increased considerably by the use of a suitable ferrite core. The number of required turns will be

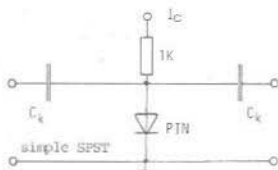
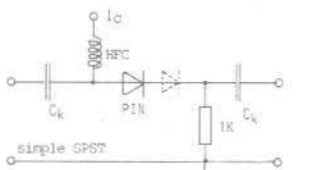


Fig. 12a:  
Simple switch SPST

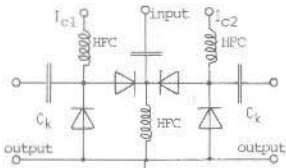
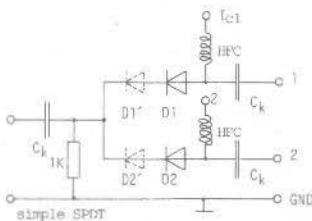


Fig. 12b:  
Simple change-over switch  
SPDT (left). The free output  
is automatically short-  
circuited. The residual RF is  
reflected (right).

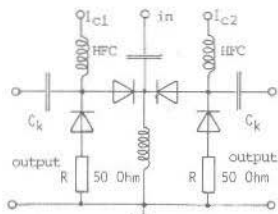
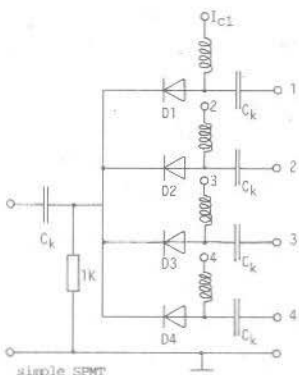


Fig. 12c:  
Simple multi-way switch  
SPMT (left). The free outputs  
must be terminated in 50  $\Omega$   
(right). The free output can be  
shorted without affecting the  
input VSWR

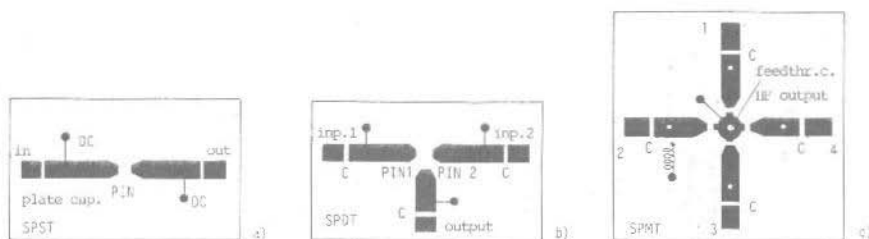


Fig. 13: Main constructional points in stripline technique

smaller and the self-resonant frequency higher. The simplified equivalent circuit of a high-frequency choke is given in fig. 11.

The HFC problem is only troublesome with wide-band systems, i.e. say 40 to 900 MHz. If only one band of interest is contemplated then the chokes described above can be used without any problems.

The cold end of the choke must be effectively RF-earthed with one, or preferably several, good-quality capacitors. Normal feed-thru' capacitors alone are usually not adequate for the job but a small value soldered in parallel should do the trick. A more complicated low-pass feed originating from Hewlett Packard is shown in fig. 10c.

### 3. PIN-DIODE SWITCH BASIC CIRCUITS

PIN diodes allow HF circuits to be realized with the same facility of those at AF. Figure 12 gives a rough review of the possibilities. In principle, these possibilities are only limited by the imagination. The following circuits may be recognized:

- Normal ON/OFF i.e. SPST switch (Single Pole Single Throw)
- Change-over SPDT switch (Single Pole Double Throw)
- Multipole SPMT switch (Single Pole Multi Throw)

In order to improve the decoupling between 'throws', the unused PIN-diode circuits may be

readily shorted to ground by means of another switch wafer. This almost guarantees that there will be no RF at the output of the unused switch-ways. Short-circuiting the unused outputs, however, means that the input resistance of the appropriate PIN-diode switch-way will tend to zero. This affects the input resistance to the switch, making it deviate from  $50\ \Omega$  and thus giving rise to power reflections. This can be undesirable, especially in systems where the modular input and output impedances require a  $50\ \Omega$  termination. In such a case it will be necessary to include a  $50\ \Omega$  resistance in the short-circuit path of the diode. Such devices are known as non-reflective switches.

In order to improve upon the PIN-diode switching performance, several of them may be connected in series. This greatly increases the isolation in the off-condition but the residual attenuation is, of course, increased. This is dealt with in ref. 3. The diagram of fig. 13 shows the practical form of some PIN switches. The stripline form is particularly well-suited for this type of switch because the characteristic impedance is very well defined at all parts. Reflective points caused by the long, thin connecting wires of the PIN diode are avoided.

Even when the conductor track width of the stripline is not exactly  $50\ \Omega$ , it is far better than a freely-wired circuit. A meaningful and effective alternative to etching the copper to form tracks is to cut them. The copper-sided board is cut into 3 mm wide strips and glued onto a conducting surface (tin plate or PCB stock). This method is very suitable for experimentation and when the testing and adjustment has been optimized, a final PCB may be etched out.

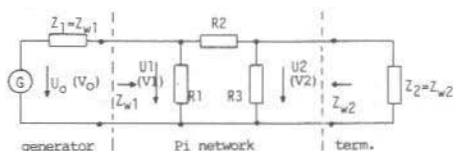


Fig. 14: Pi-attenuator with source and load resistances

#### 4. FIXED ATTENUATORS IN THE PI-TECHNIQUE

In order to realize an attenuator network which can be stepped, the individual elements must be independent of frequency. The Pi circuit offers the best solution in the UHF/VHF range as a rule. The formulae, used to calculate the elemental resistance, are given below for the sake of completeness. The Pi circuit of fig. 14 applies:—

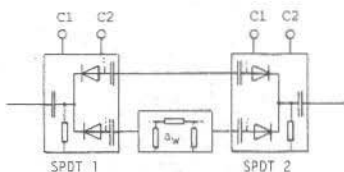


Fig. 15a: Switched four-pole with simple SPDT switch

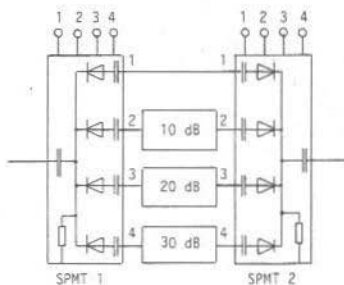


Fig. 15b: With the SPMT switch several attenuator pads may be selected. The poor isolation, however, causes problems

a) Unsymmetrical

$$R2 = \frac{n^2 - V}{2n} \cdot Z_{w2}$$

$$R1 = \frac{n^2 - V}{\frac{n^2 + V}{Z_{w1}} - \frac{2 \cdot n}{Z_{w2}}}$$

$$V = Z_{w1} / Z_{w2}$$

$$n = U1 / U2$$

$$n = 10^{aw/20} \cdot \sqrt{V}$$

b) Symmetrical

$$R1 = \frac{n^2 - 1}{2n} \cdot Z_w$$

$$R2 = \frac{n + 1}{n - 1} \cdot Z_w$$

$$V = Z_{w1} / Z_{w2} = 1$$

$$R1 = R3$$

$$n = U1 / U2$$

$$n = 10^{aw/20}$$

The impatient practical constructor should, however, look up the following table. It gives attenuation values up to 20 dB. If larger values of total attenuation are required, they should be realised by connecting several values in series to make up the total value i.e. no single pad should have a greater attenuation than 20 dB, e.g. a total value of 35 dB could be made of a 15 dB and a 20 dB pad. At single attenuations above 20 dB, the resistors R1 and R3 are tending to low-value resistances and R2 is tending towards being a high-value resistance. This means that the reactance of the self-capacitance across R2 tends to the same order of R2 itself thus tending to leak the RF over the attenuator and eventually nullifying its effect as the frequency increases to around 1 GHz.

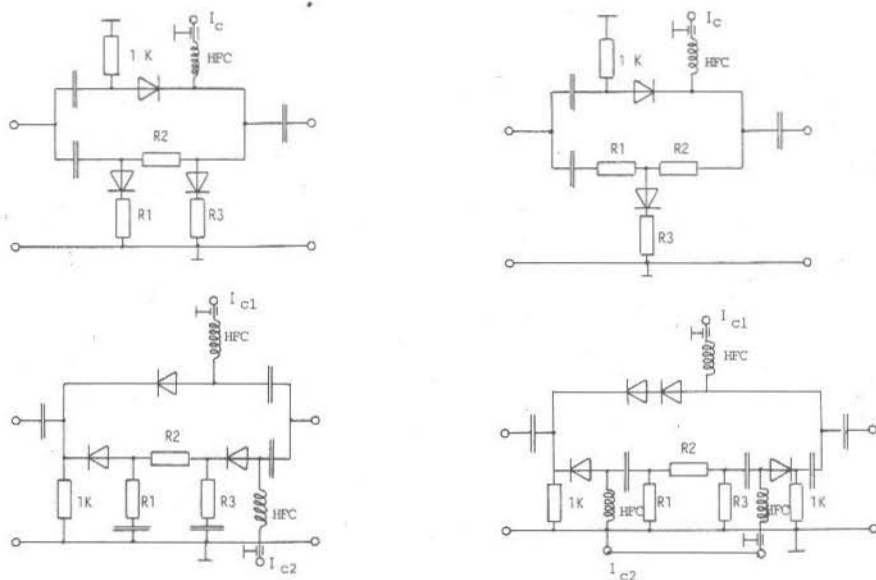


Fig. 16: Four simple methods of switching a four-pole network

aw / dB	R1, R3 / $\Omega$		R2 / $\Omega$
1 dB	896.5	$\Omega$	5.8 $\Omega$
2 dB	436.2	$\Omega$	11.6 $\Omega$
3 dB	292.4	$\Omega$	17.6 $\Omega$
4 dB	221.0	$\Omega$	23.8 $\Omega$
5 dB	178.5	$\Omega$	30.4 $\Omega$
6 dB	150.5	$\Omega$	37.4 $\Omega$
7 dB	130.7	$\Omega$	44.8 $\Omega$
8 dB	116.1	$\Omega$	52.8 $\Omega$
9 dB	105.0	$\Omega$	61.6 $\Omega$
10 dB	96.2	$\Omega$	71.2 $\Omega$
11 dB	89.2	$\Omega$	81.7 $\Omega$
12 dB	83.5	$\Omega$	93.2 $\Omega$
13 dB	78.8	$\Omega$	106.1 $\Omega$
14 dB	74.9	$\Omega$	120.3 $\Omega$
15 dB	71.6	$\Omega$	136.1 $\Omega$
16 dB	68.8	$\Omega$	153.8 $\Omega$
17 dB	66.4	$\Omega$	173.5 $\Omega$
18 dB	64.4	$\Omega$	195.4 $\Omega$
19 dB	62.6	$\Omega$	220.0 $\Omega$
20 dB	61.1	$\Omega$	247.5 $\Omega$

Table 1: Determination of the resistors for a 50  $\Omega$  pi-attenuator

$$Z_{W1} = Z_{W2} = 50 \Omega$$

## 5. REALIZING A SWITCHED ATTENUATOR

By means of two change-over switches – SPDT or SPMT – a four-pole network may be switched in quite a simple fashion.

If the attenuators are switched in series then the SPDT switch of fig. 15a is required.

Parallel switching of four-pole networks makes use of the SPMT switches as in fig. 15b.

In order to switch a four-pole network on or off two SPDT switches are required. It is a simpler process when one of the switch functions is combined with the four-pole network itself. The principle is always the same, namely:

- Input and output of the network are switched at high impedance.
- The high-impedance network can be short-circuited.

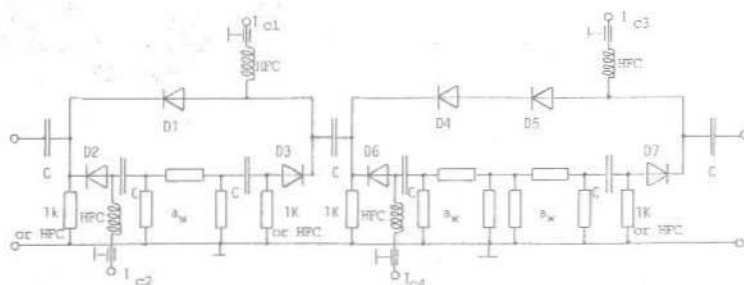


Fig. 17: Switched attenuator 0/20/40 dB (2 x 20 dB attenuators)

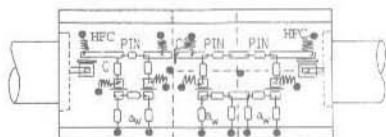
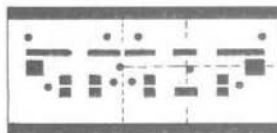
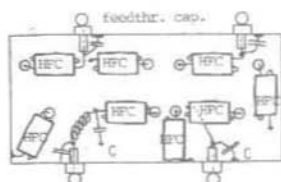


Fig. 18: Suggested construction for an electrically-switched attenuator in strip-line technique

1. Unit: a to 20 dB
2. Unit: a to 40 dB (i.e. 2 x 20 dB)

The review of fig. 16 shows a few of the possibilities. Fig. 16a and 16b: These depict the introduction of the control source to effect the switching. This is accomplished by changing the polarity of the control current  $I_c$ , the attenuator being either activated or short-circuited. The control-current source must be able to reverse the polarity of the output current.

Fig. 16c and 16d: The polarity here plays no part in the switching, it is done simply by the presence or otherwise of the input to be switched.

The circuit of fig. 17 has been used for some time now. The resistances of the Pi-network are galvanically separated in order that no DC can flow, otherwise the resistors would be overheated. The method of operation of this 20 dB attenuator is as follows:—

a) No attenuation: A 12 V potential is applied to the control input and diode D1 conducts. Diodes D2/D3 then receive a reverse bias. The attenuator input is now high impedance. Owing to a negative bias on control input 2, diode D2 switches to a slightly higher impedance. The lower the impedance of D1 and the higher the impedance of diodes D2/D3, the better the change-over action.

b) Attenuation selected: The control voltage potential is changed. Control input 1 now receives - 12 V, diode D1 is blocked and diode D3 conducts. A potential of + 12 V at control input 2 allows D2 to become conductive and the four-pole network is switched into circuit. The desired value of attenuation is now dependent upon the negative bias on diode D1.



Both of the 1 k $\Omega$  HF resistors used for the control-current feed can be replaced by high-frequency chokes. The diode current can then be increased thus achieving the maximal performance.

The isolation of the shunt diode is not able to bridge attenuations of more than about 30 dB. This was determined by experiments with the BA 379/479. Fixed attenuators up to 20 dB are able to be shunted with a PIN diode but higher values, say up to 40 dB, may be bridged with two PIN diodes in series in order to increase the isolation.

A switchable 20/40 dB attenuator is shown in **fig. 17**. The 40 dB is realized by 2 x 20 dB elements for the reasons expounded earlier. A metal screening wall divides the two four-pole elements thus preventing mutual interference. This measure enables the full 40 dB to be held constant over the whole of the frequency range.

A step attenuator may be formed by the series of switchable fixed elements.

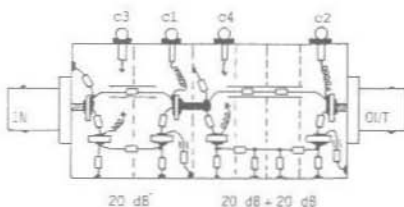
In order to adjust the attenuation to the desired value, the necessary electronics must be developed — but more of that later.

## 6. A PRACTICAL PIN-DIODE ATTENUATOR

Stripline techniques are used for a practical attenuator. The stripline's characteristic impedance depends upon the basic PCB material and from the width of the copper track. Using normal 1.5 mm thick epoxy, the following values may be taken:

Characteristic Impedance $Z_w$	PCB track-width
75 $\Omega$	1.3 mm
60 $\Omega$	1.9 mm
50 $\Omega$	2.7 mm

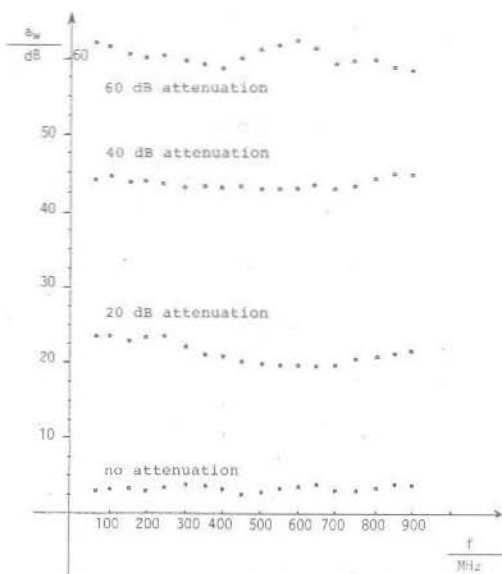
**Fig. 18** shows a possible layout, again in strip-line technique. The printed circuit board fits into a proprietary tin-plate housing. The layout and the supply wiring are not quite optimal for the in-



**Fig. 19: Suggested construction for a step-switched attenuator in coaxial form. Not usually employed for wideband operation**

tended frequency range, but nevertheless, the module gives very good results.

If it is preferred to construct the PIN switch in a tin-plate box using free wiring, it is best to use the coaxial form of construction — the PIN diode running coaxially in a copper tube as in **fig. 19**. The diode lead wires must not be left too long as this will adversely effect the characteristic imped-



**Fig. 20: Test results for an experimentally-constructed switched attenuator as described in text. (20 mA control current)**

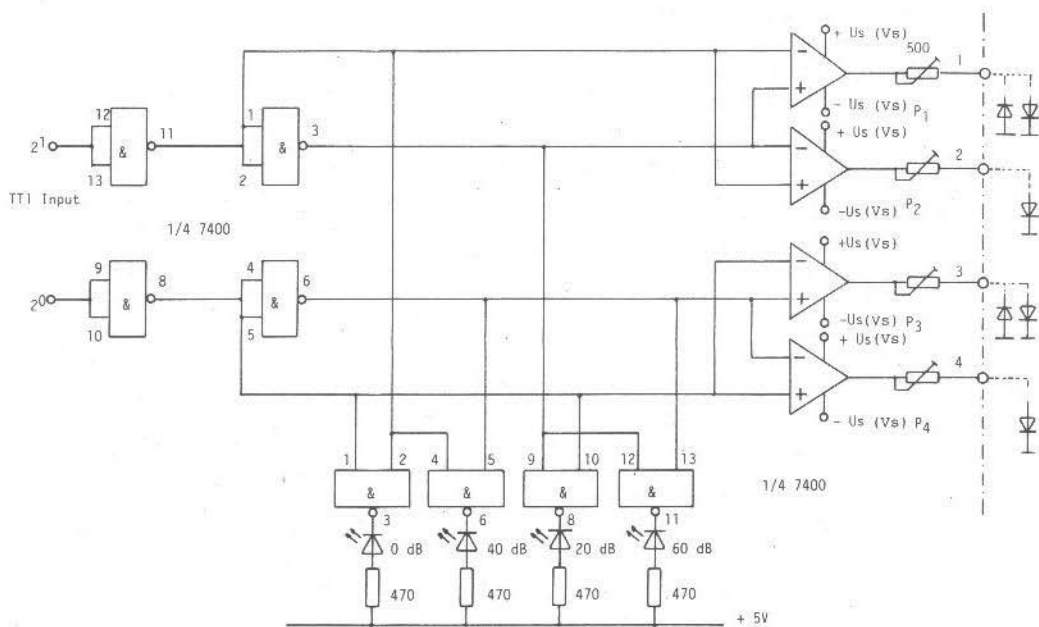


Fig. 21: Simple interface for the PIN-diode switch

Supply voltage for 7400: + 5 V  
for LM 324:  $\pm 12$  V  
for LEDs: + 5 V

ance. As well as the danger of HF reflection points, mentioned earlier, there is also skin-effect losses to be considered. The higher the working frequency, the more these effects become prominent.

The great advantage of the stripline approach is, that at all points along the line, the characteristic impedance is closely defined. Only the components can cause trouble in this respect but the amateur can do nothing about it normally. The special chip components which harmonize with the stripline technique and homogenize the construction, are not universally available. The test results show, however, that even without special components a good attenuator can be constructed.

### 6.1. The Printed Circuit Board

The copper under the Pi elements is not, in this version, etched away. The capacitance to ground tends to linearize the attenuation curve. All DC

supply lines are effected via HFCs and the feed-in is carried out on the solder side by means of small air-supported chokes (4 turns wound on a 3.2 mm drill). The feed-through capacitors must be shunted by small high-quality capacitors in order to improve the low-pass effect – the value is uncritical, but in the nF region.

1 nF plate capacitors are used for coupling purposes. The 1/4 W resistors of the Pi network and also the PIN diodes are soldered directly on the top of the board's surface, no holes being necessary for the leads. All the cold ends of the Pi-networks are however, connected through to the ground plane via drilled holes. The screening wall is important in the interests of a good attenuation characteristic.

### 6.2. Test Results

The step-switched attenuator was constructed according to the diagrams of **figs. 17 and 18** and supplied the following results:



The precision, i.e. the linearity of attenuation over the entire frequency range as well as its stable input return-loss is dependent upon the method of construction and the components utilized. The most important single factor is the method of introducing the DC control current.

Using the recommended construction, the test results depend heavily upon the manner in which the DC was fed in. The test results for the given construction can be seen in **fig. 20**. It indicates the attenuation versus frequency for various system attenuations. When zero attenuation is selected, the residual attenuation is approximately 2 dB.

### 6.3. Parts List

All the low-pass filters allow a control current of 50 mA to be achieved.

- 1 Tin-plate box 74 x 37 x 30 mm
- 2 N-panel mounting connectors
- 1 Printed circuit board, two-sided etched as in **fig. 18**
- Screening walls, as in **fig. 18**
- 8 Valvo 6-hole wideband VHF chokes
- 8 Self-supporting 4 turn 3 mm dia chokes
- 7 Plate capacitors, approx. 1.5 nF
- 7 PIN diodes BA 479 G;  $I_{max} = 50$  mA (only 25 mA used here)
- 4 Feed-through capacitors approx. 1 nF or more
- 9 Resistors (3 x 3 resistors of the 20 dB Pi-networks of table 1)

Other items: Additional chokes, ferrite beads and capacitors as required in order to improve the low-pass filters.

## 7. SIMPLE CONTROL CIRCUITS

The electronically-switched attenuator requires an additional supply which is able to switch the polarity under the influence of TTL potentials.

The simplest solution is to use an operational amplifier in a comparator circuit. According to the input signal level, the output delivers a voltage which is either positive or negative.

A simple interface is shown in **fig. 21** which

utilizes the 4 x operational amplifier LM 324. This is able to deliver the required 20 mA, or more, current required but if a power op-amp is available, so much the better.

The two TTL inputs of the interface allow four possibilities. The selected attenuation is indicated by an LED. By means of a pre-set potentiometer in the operational amplifier output, the required control current can be set as desired. The four outputs are connected with the appropriate control inputs of the attenuator module.

## 8. CONCLUSION

The electronically-switched attenuators are also usable in the high-frequency range. The control current must, however, be tailored to match the working frequency. The PIN-diode data sheet must be consulted to determine the lowest-permissible frequency of operation.

This article cannot represent all that one needs to know on the subject of PIN diodes for amateur purposes but it might at least serve to stimulate the constructor into practical experimentation. If the version described here is faithfully copied, a fully functional instrument will be acquired — and with good specifications.

## 9. REFERENCES

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